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Groundwater Resources of the Lake Saint-Martin Area, Manitoba

Sheet 6 of 6

Aquifer Productivity and Vulnerability

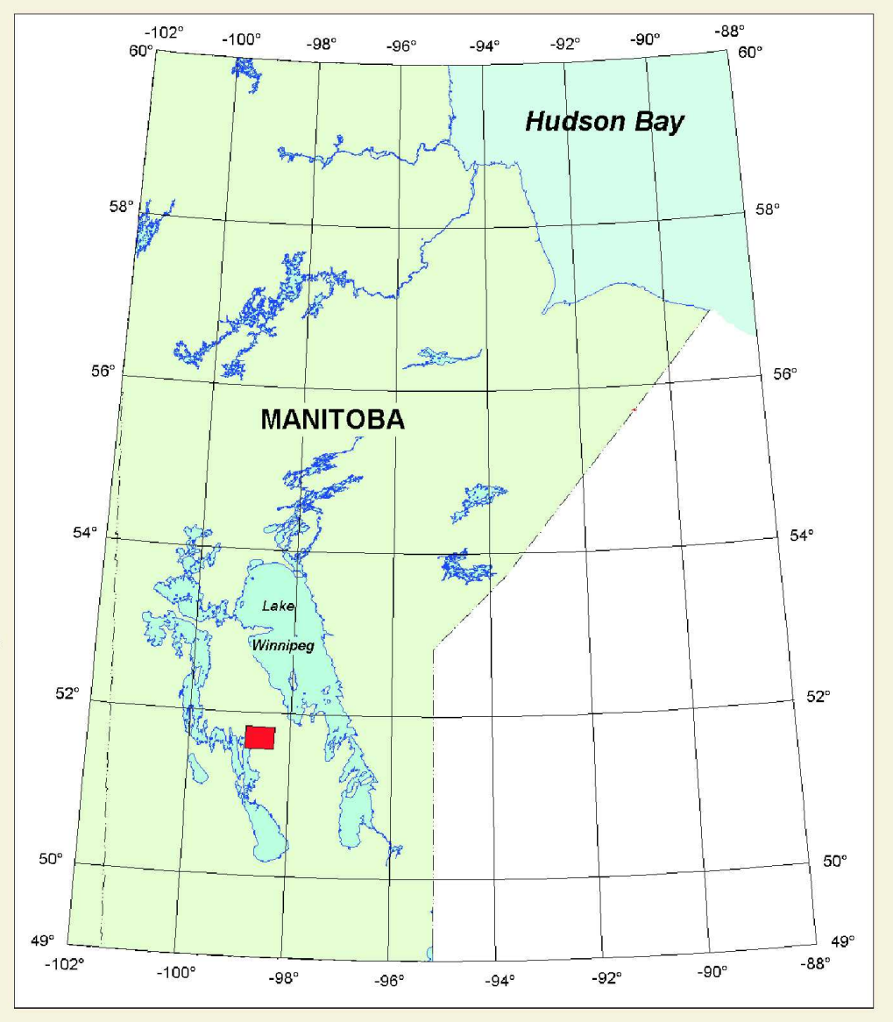

Figure 1: Location of study area

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Map Notes

Introduction

The bedrock aquifers of the Lake Saint-Martin area (Figure 1) were mapped previously by Betcher (1987) at a scale of 1:250 000. The maps presented here are based on more detailed groundwater investigations in the area carried out by the Geological Survey of Canada as well as information contained in the provincial water well records. These maps are intended to characterize the productivity of area aquifers as well as their vulnerability to impact from nitrates, a ubiquitous groundwater contaminant with potentially serious effects on human health.

Aquifer Productivity

The productivity of aquifers, or their ability to supply groundwater, depends on a number of factors including their hydraulic conductivity, specific storage and thickness, in addition to the amount of recharge they receive from precipitation. A simple but useful way of characterizing aquifer productivity is through the measurements of specific capacity reported in provincial water well records. These measurements are obtained from pumping tests performed by water well drillers when a well is completed. The well is pumped at a constant rate for a fixed period of time and water levels in the well are measured at the beginning and at the end of pumping. The specific capacity of the well is obtained by dividing the pumping rate by the observed draw down of the water level. For this study, 234 usable measurements were available to map specific capacity throughout the area. Well locations correspond to centers of quarter sections. In order to assist interpretation of the specific capacity map, a map of well depths is also provided.

Figure 2 shows a map of specific capacity variations over the study area. Corresponding well depths are mapped in Figure 3. High specific capacities are found at shallow depths in wells along the shore of Lake Manitoba. These wells are probably tapping a highly-permeable brecciated layer often found at the base of the Devonian Ashern Formation. High specific capacities in shallow wells northwest of Lake Pineimuta are probably associated with karstic features reported by drillers in this area. With the exception of one well tapping the carbonate breccia unit south of Gypsumville, specific capacities within the Impact Structure are lower and well depths are greater. Moderately deep wells are usually tapping sandy layers within the red bed aquitard whereas very deep wells are tapping granitic micro-breccia. The median specific capacity outside the Impact Structure is 30.7 m^3 /day/m compared to a value of 14.4 m^3 /day/m within.

Aquifer Vulnerability

The likelyhood of an aquifer becoming contaminated from domestic, agricultural or industrial pollutants depends on factors related to human activity, such as land use, and factors related to the intrinsic susceptibility of the aquifer to contamination. These latter factors are summarized in the acronym DRASTIC (Aller et al., 1985) which stands for Depth to water table, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone media and hydraulic Conductivity of the aquifer. Maps of aquifer contamination likelyhood or vulnerability are useful to planners in order to minimize the risk that proposed development may not threaten groundwater resources. While there are many different ways of assessing groundwater vulnerability (NAS, 1993), it is not a property that can be measured directly. Rather, it is a statement about the probability of future contamination occurring based on factors that are measurable, such as the DRASTIC parameters. Given the rural nature of the study area, the contaminant of greatest relevance is nitrate. Therefore, vulnerability is defined here as the probability (ranging between 0 and 1) of observing nitrate concentrations in excess of a threshold of 4 mg/L for background levels. Details of the vulnerability mapping method are provided in the Map Production Notes below. The map of aquifer vulnerability thus obtained is shown in Figure 4. For comparison, a map of observed nitrate concentrations is shown in Figure 5.

Figure 4 shows that higher aquifer vulnerabilities are closely associated with recharge areas, where water table depths are greater and overburden thicknesses are lower. Surficial deposits in these areas are either absent or consist of thin layers of till, glacio-fluvial sands or gravels. Comparison with Figure 5 shows that most areas of high vulnerability coincide with areas known to be impacted by nitrates such as Gypsumville, the Pinaymootang (Fairford) reserve and the northern tip of the ridge between Lake Pineimuta and Lake Manitoba. Conversely, some areas impacted by nitrates, east of Lake Pineimuta, have only moderate levels of vulnerability. Nitrate levels in these impacted areas occasionally exceed the Health Canada (2002) limit of 45 mg/L. Other areas of high vulnerability do not exhibit elevated nitrate levels simply because they are largely uninhabited. The most densely populated portions of the study area, on the reserves of the Lake Saint-Martin and Little Saskatchewan First Nations, show very low aquifer vulnerabilities and nitrate levels. This is because of the shallow water table and thick overburden in these areas.

Map Production Notes

During the month of August in 1998, 384 water samples were collected from wells and streams within the study area. Water well sample locations are marked on the figures. All samples were analyzed for major cations and anions, as well as trace and ultra-trace metal contents. Waters at 42 sites were sampled for stable isotope analyses. Parameters measured in the field include pH, Eh, conductivity, dissolved oxygen and temperature. All survey results are publicly available from the authors at the GSC or from Water Branch of Manitoba Conservation. Data used in the mapping of specific capacity and well depth are from the provincial water well records. These well data are assigned the spatial coordinates of the center of their quarter section.

Mapping of specific capacity, well depth and nitrate concentration was performed using the geostatistical spatial interpolation method known as Indicator Kriging (Deutsch and Journel, 1992). Because of the high density of sample locations in more populated areas, a preliminary cell declustering was carried out prior to kriging. This involved pooling all samples falling within the same quarter section (64.64 ha) cell. Interpolation by kriging was then performed on a regular 300m by 300m grid using a single global search neighborhood encompassing all pooled data locations.

It is important to recognize that kriged estimates of aquifer parameters, like those obtained by other spatial interpolation methods, are smoothed compared to actual values. In other words, the maps of parameters shown here represent general trends in values and not their true spatial variability. Thus, individual well analyses should not be expected to agree exactly with mapped values at the same location. The uncertainty in parameter estimates is lower in the central portion of the study area, where well control is better. Where well control is sparse, uncertainty is higher and results should be interpreted with caution. Portions of the study area where uncertainty is unacceptably large are left blank.

Mapping of aquifer vulnerability involved two steps. The first step was to develop a logistic regression model (Eckhardt and Stackelberg, 1995; Nolan, 2001) for predicting vulnerability, expressed here as the probability “p(x)” of exceeding a threshold nitrate concentration of 4 mg/L in groundwater from a well at location “x”. The most useful predictor variables were found to be overburden thickness “T(x)” and water level depth “W(x)” at the well. Based on the data set of 384 groundwater samples, the following logistic regression model was fitted:

$$p(x) = \exp[\, g(x) \,] / [\, 1 + \exp[\, g(x) \,] $$

Where

$$g(x) = 3.757 - 3.051.\ln[T(x)] + 3.327.\ln[W(x)] - 0.331.W(x).\ln[W(x)]$$

The first term of the model is simply a constant. The second term shows that aquifer vulnerability decreases with increasing logarithm of overburden thickness. The third term shows that vulnerability increases with the logarithm of depth to water. A similar result was obtained by Nolan (2001). Although counter-intuitive, it can be explained by the fact that vulnerable wells are found in recharge areas with moderate to deep water levels. Conversely, low-vulnerability wells are found in discharge areas with shallow water levels, where nitrate reduction may take place in the presence of organic deposits. The last term in the model represents a non-linear effect that gradually offsets the increase in vulnerability with water level depth associated with the previous term. For water level depths greater than 10m, aquifer vulnerability begins to decrease as one would expect with a thick unsaturated zone. The second step in the production of the vulnerability map was to apply the logistic regression model systematically to water level depth and overburden thickness values at all grid node locations on the maps of sheets 3 and 2 of this Open File report, respectively. This way, aquifer vulnerability was mapped throughout the study area, including areas that are uninhabited or where development has not yet occurred.

References

Aller, L., T. Bennett, J.H. Lehr and R.J. Petty (1985): DRASTIC-A standardized system for evaluating ground water pollution potential using hydrogeologic settings, U.S. EPA, Robert S. Kerr Environmental Research Laboratory, Office of Research and Development, EPA/600/2-85/018.

Betcher, R.N. (1987): Groundwater Availability Map Series : Dauphin Lake (620), Water Resources Branch, Manitoba Natural Resources, Winnipeg, Manitoba.

Deutsch, C.V and A.G. Journel (1992): GSLIB : Geostatistical Software Library and User's Guide, Oxford University Press, New York.

Eckhardt, D.A.V. and P.E. Stackelberg (1995) Relation of ground-water quality to land use on Long Island, New York, Ground Water, 33(6), 1019-1033.

Health Canada (2002): Summary of Guidelines for Canadian Drinking Water Quality, prepared by the Federal-Provincial-Territorial Committee on Drinking Water, Safe Environment Programme, www.hc-sc.ca/waterquality

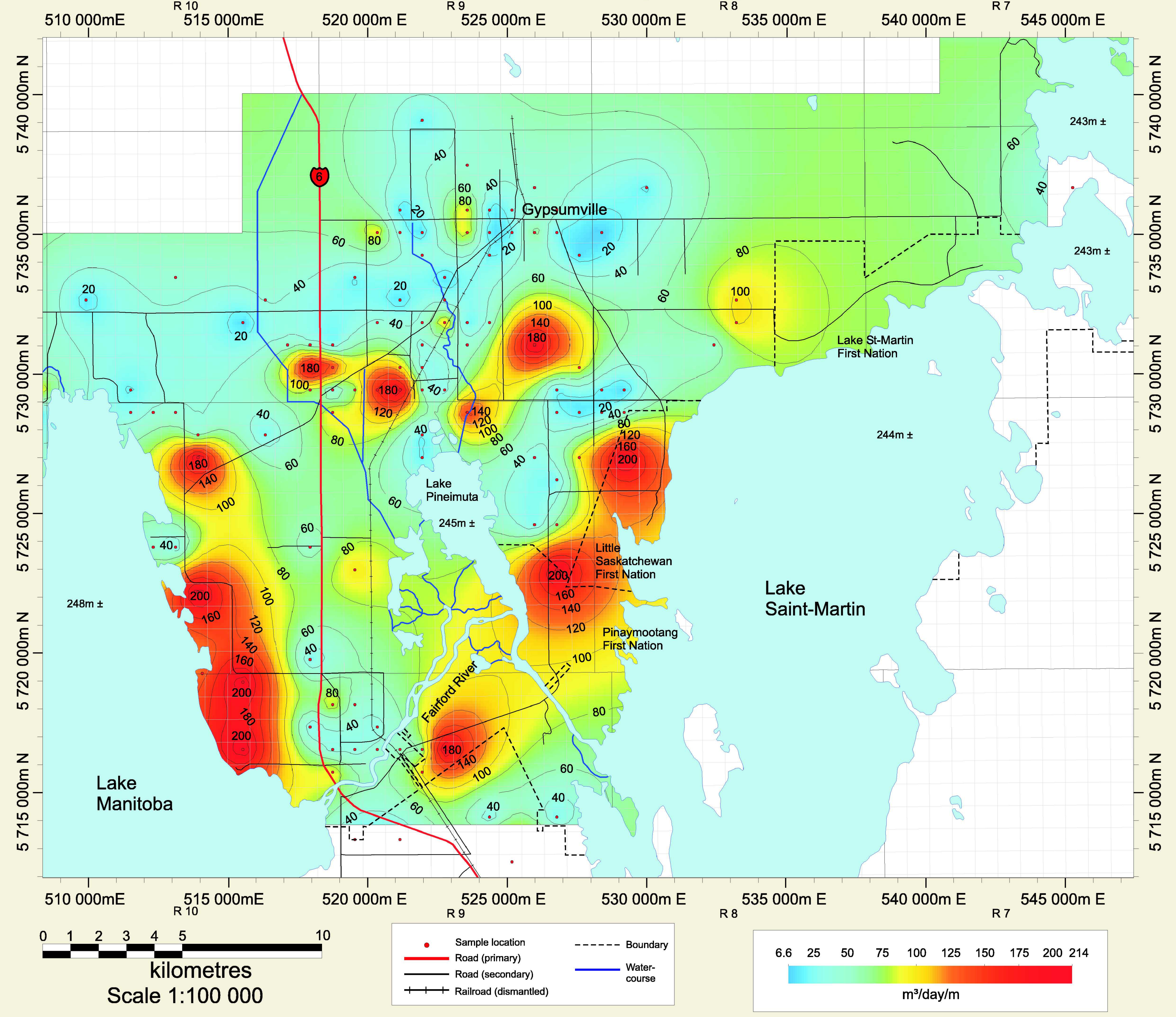
National Academy of Sciences (1993) Ground water vulnerability assessment: Predicting relative contamination potential under conditions of uncertainty, National Academy Press, Washington DC.

Nolan, B.T. (2001) Relating nitrogen sources and aquifer susceptibility to nitrate in shallow ground waters of the United States, Ground Water, 39(2), 290-299.

AQUIFER PRODUCTIVITY

Figure 2

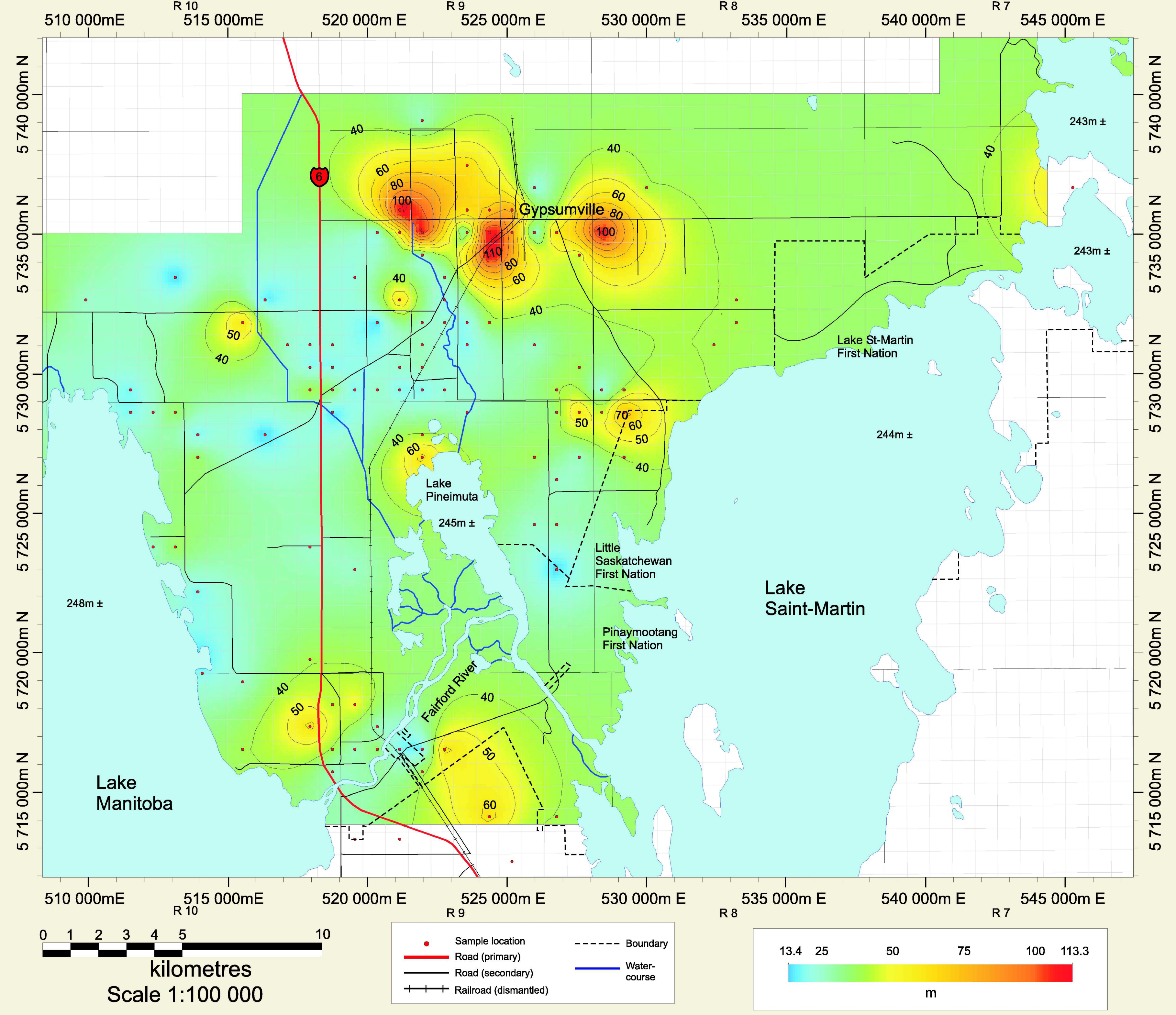
Specific Capacity



Contour interval 20

Figure 3

Well Depth

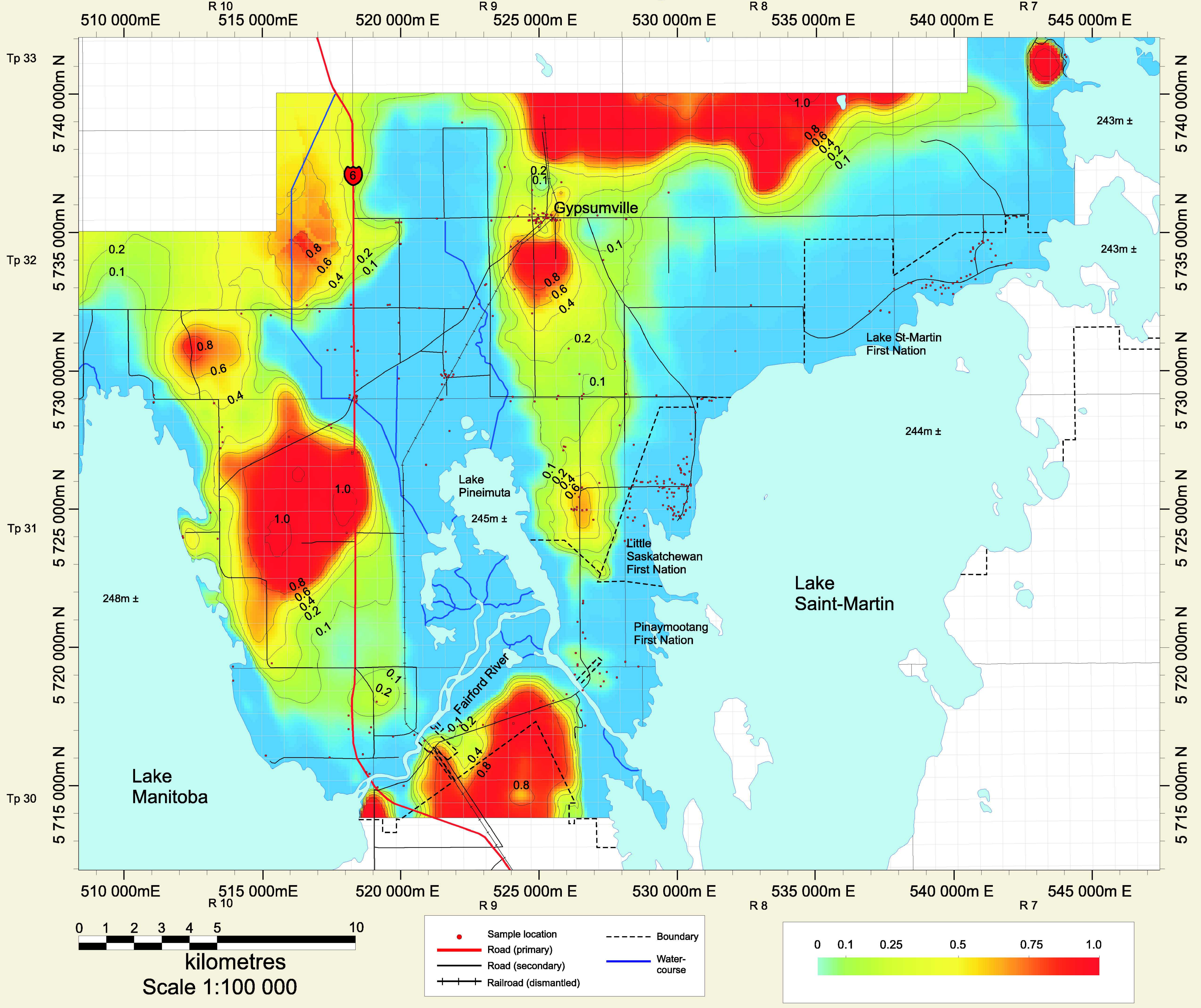


Contour interval 10 m

AQUIFER VULNERABILITY

Figure 4

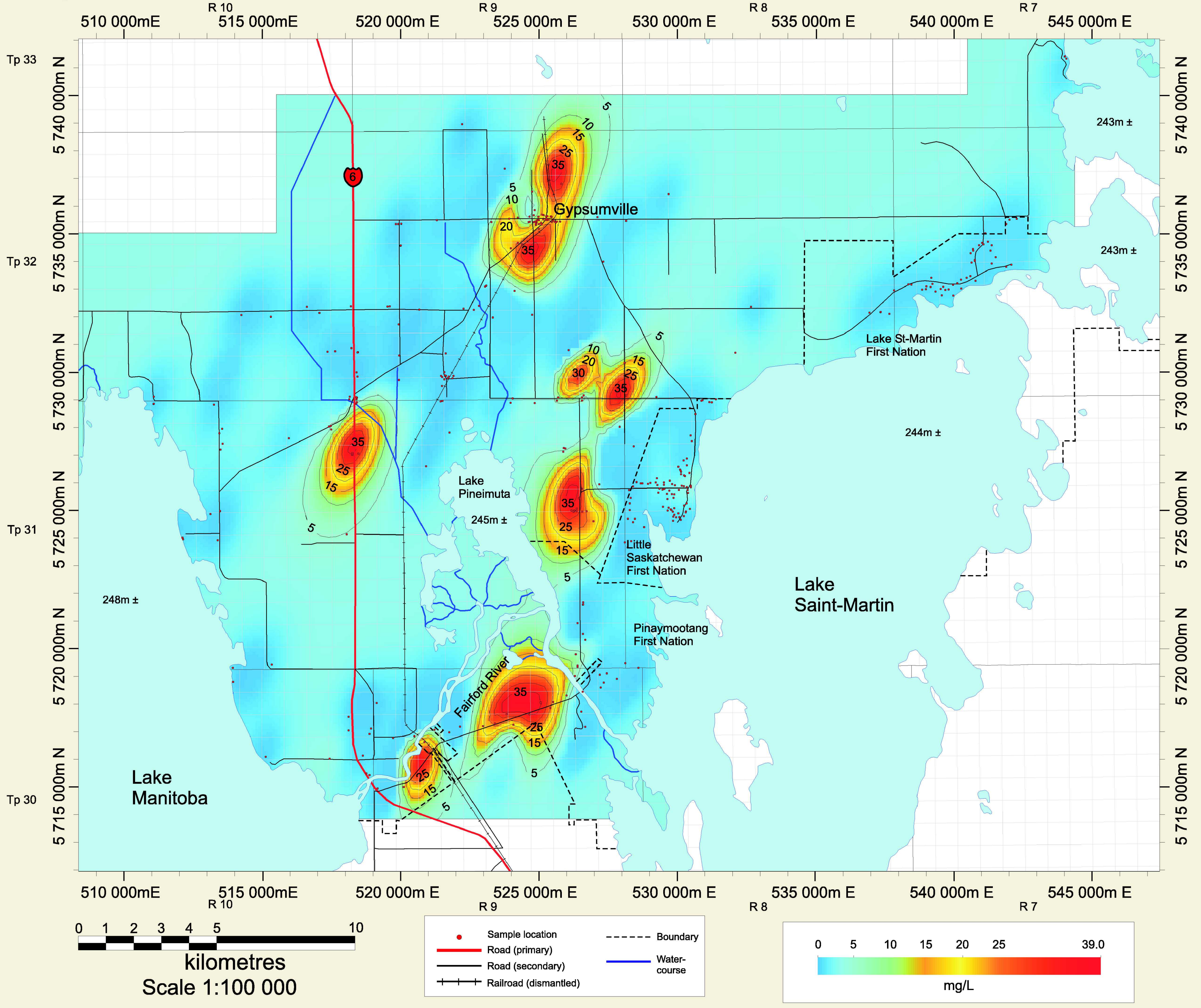
Vulnerability Index



Contour interval 0.2

Figure 5

Nitrate



Contour interval 5 mg/L